

# Eclipses, transits and variability of white dwarf stars with Kepler

Matt Burleigh, Francesca Faedi, Jay Holberg, Ian Braker, Sarah Casewell, Katherine Lawrie, Mike Goad, Martin Barstow

The small size of a white dwarf (WD) star ( $\sim 1R_{\text{Earth}}$ ) implies that any sub-stellar or gas giant companion at suitable orbital inclination will completely eclipse it, while terrestrial bodies smaller than the Moon, including asteroids, will still produce transits that are detectable in high signal/noise light-curves. We utilised data from the SuperWASP survey to conduct the first large, systematic search for such companions in close (few hours) orbits to a few hundred WDs (e.g. Faedi et al. 2009, 2011). Subsequently, Agol (2011) defined a habitable zone (HZ) for WDs extending from 0.005 AU to 0.02 AU and periods from 4 – 30 hours, for stars older than  $\sim 1$  Gyr. We have found no such companions in SuperWASP data to date, but the resulting limits on terrestrial planets within Agol’s HZ are poorly constrained (Fig. 7, Faedi et al. 2011).

Whether such planets actually exist around WDs is an open question. Those caught within the expanding envelope of an AGB star will be destroyed. However, the presence of debris disks around a few % of WDs (Farihi et al. 2011, Barber et al. 2012), and accreted metals in the photospheres of a surprisingly large fraction of such stars ( $\sim 25\%$  at  $\sim 1$  Gyr, Zuckerman et al. 2003) demonstrates that surviving asteroids and terrestrial planets must be perturbed into orbits that take them close to the central WD, where they are tidally disrupted. Even so, it appears dynamically difficult, though not impossible, to perturb them into stable, circularised orbits within the WD HZ. Alternatively, 2nd generation planets may be created from material ejected after the AGB phase.

The Kepler 2 mission is an ideal opportunity to search the HZs of a statistically significant (500 – 1000) sample of WDs for terrestrial planets. Any discovery would provide vital data and a significant challenge to dynamicists and theoreticians, just as the unexpected discovery of hot Jupiters did in the 1990s. A single detection would then open the exciting possibility of studying the atmosphere of a nearby terrestrial world through spectroscopy with JWST (Loeb & Maoz 2013).

A Kepler survey of WDs opens up other serendipitous science than just the exciting, but perhaps tantalising prize of a terrestrial planet. Besides pulsating WDs, which can be studied in exquisite detail with high cadence mode observations, other variable examples will be discovered. Recently, Beuermann et al. (2013) discovered the first eclipsing, detached WD + brown dwarf (BD) system, and Casewell et al. (2012) found probably the lowest mass close companion to a white dwarf ( $25 - 30M_{\text{Jup}}$ ). Both BDs likely survived common envelope evolution, but what is the lowest mass object that can do so, and will it be revealed through eclipses of the WD? One of the intriguing discoveries from the original Kepler mission was the unexpected  $\sim 6$  hr,  $\sim 5\%$  peak-to-peak variability of the 17th mag hot WD BOKS 53856 (Holberg & Howell 2011). This star is weakly magnetic, but with a fully radiative atmosphere the mechanism for causing these large modulations is not immediately apparent. Perhaps BOKS 53856 is accreting from an orbiting reservoir of planetary debris? It is likely more unexpected variables await discovery.

The total eclipse of an Earth-sized WD by a Jovian or BD sized companion in a few hour orbit will last  $\approx 5$  mins. In a 30 min low cadence (LC) observation this will be diluted to  $\approx 17\%$ . An eclipse by an  $\sim 1R_{\text{Earth}}$  terrestrial companion in the HZ would last  $\approx 2.5$  min, diluted to  $\approx 8\%$  in a LC datapoint. These can be compared to the expected Kepler 2 mission sensitivity at magnitude 18.5 of  $\sim 60,000$ ppm (6%). Even at this faint magnitude, the Jovian sized object would be comfortably visible at  $3\sigma$  confidence in a single datapoint, while the Earth-sized object would also be detectable, especially if many such eclipses/transits are observed and suitably phase-folded.

We have compiled a target list of 39 spectroscopically identified WDs brighter than  $g, V = 18.5$  from the McCook & Sion and SDSS catalogues that can be observed at LC by Kepler 2 in Field 1. We have omitted all known unresolved binaries, and potential targets within a few arcsecs of another, brighter source. We have also noted the few objects with reasonable proper motions in the accompanying target file.